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ESTCP Live Site Demonstrations Massachusetts Military Reservations Camp Edwards, MA

ESTCP MR-1365
Demonstration Data Report
Central Impact Area
TEMTADS MP 2×2 Cart Survey

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14. ABSTRACT

NRL and NAEVA Geophysics conducted a cued classification survey on the remaining 1.75 acres of the 3-acre man-portable subarea selected from within the 330-acre CIA demonstration site. The 2012 NRL survey investigated 1,005 anomalies in the northern 1.25 acres of the man-portable area. Cued data collection was conducted for the remaining 1,429 anomalies previously identified. This survey used the NRL TEMTADS MP 2×2 Cart (MP System) operating in litter-carry mode. Characterization of the system responses to the Targets of Interest (TOIs) was based on previously acquired TEMTADS reference data. These data were collected in accordance with the overall study objectives and demonstration plan. Unlike the 2012 demonstration, classification analysis of the interrogated anomalies was conducted as well. This document describes the results of the demonstation.

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Classification	Electromagnetic induction (EMI)	Massachusetts Military Reservation, MA
Unexploded ordnance (UXO)	Transient electromagnetic induction (TEM)	

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Acronyms

Abbreviation	Definition
AOL	Advanced Ordnance Locator
APG	Aberdeen Proving Ground
ASCII	American Standard Code for Information Interchange
CIA	Central Impact Area
EMI	Electro-Magnetic Induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
IVS	Instrument Verification Strip
MMR	Massachusetts Military Reservation
MP	Man-Portable
MR	Munitions Response
MTADS	Multi-sensor Towed Array Detection System
NRL	Naval Research Laboratory
POC	Point of Contact
QC	Quality Control
RMS	Root-Mean-Squared
Rx	Receiver
SAIC	Science Applications International Corporation
TEM	Time-domain Electro-Magnetic
TEMTADS	Time-domain Electro-Magnetic MTADS
TOI	Target of Interest
Tx	Transmit(ter)
UXO	Unexploded Ordnance

1.0 INTRODUCTION

1.1 ORGANIZATION OF THIS DOCUMENT

This report details the participation of the Naval Research Laboratory (NRL) Man-Portable Electromagnetic Induction Array for UXO Detection and Discrimination, or TEMTADS Man-Portable (MP) 2x2 Cart, in the Environmental Security Technology Certification Program (ESTCP) Munitions Response Live Site Demonstration at the Central Impact Area (CIA), Massachusetts Military Reservation (MMR), located at Camp Edwards, MA in 2013. The 2013 demonstration completed the effort begun in 2012. To limit the repetition of information, Study- and site- specific information that is presented in the ESTCP Live Site Demonstrations Plan [1] is noted and not repeated in this document.

1.2 STUDY BACKGROUND AND OBJECTIVES

Please refer to the ESTCP Live Site Demonstrations Plan for the MMR CIA [1].

1.3 SPECIFIC OBJECTIVES OF DEMONSTRATION

As part of the ESTCP Live Site Demonstrations, NRL and NAVEA Geophysics conducted a cued classification survey on the remaining 1.75 acres of the 3-acre man-portable subarea selected from within the 330-acre CIA demonstration site. The 2012 NRL survey investigated 1,005 anomalies in the northern 1.25 acres of the man-portable area. Cued data collection was conducted for the remaining 1,429 anomalies previously identified from an EM61-MK2 cart survey conducted in 2012 by National Guard Bureau contractor TetraTech. This survey used the NRL TEMTADS MP 2x2 Cart (MP System) operating in litter-carry mode. Characterization of the system responses to the Targets of Interest (TOIs) was based on previously acquired TEMTADS reference data. These data were collected in accordance with the overall study objectives and demonstration plan. Unlike the 2012 demonstration, classification analysis of the interrogated anomalies was conducted as well. This document describes the results of the demonstration.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

2.1.1 TEMTADS/3D EMI Sensors

The original design of the MP system utilized the standard TEMTADS Electromagnetic Induction (EMI) sensor. Based on the results of the MP system demonstration at the Aberdeen Proving Ground (APG) Standardized UXO Test Site in August, 2010 [2,3], revision of the sensor technology was indicated. A modified version of the sensor element was designed and built, replacing the single, vertical-axis receiver coil of the original sensor with a three-axis

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receiver cube. These receiver cubes are similar in design to those used in the second-generation Advanced Ordnance Locator (AOL) and the Geometrics MetalMapper (ESTCP MR-200603) system with dimensions of 8 cm rather than 10 cm. The CRREL MPV2 system (ESTCP MR-201005) uses an array of five identical 8 cm receiver cubes and a circular transmitter coil. The new sensor elements are designed to have the same form factor as the original, aiding in system integration. A TEMTADS/3D coil under construction is shown in Figure 2-1.

Figure 2-1 – Individual TEMTADS/3D EMI sensor with 3-axis receiver under construction.

Minor modifications were made to the AOL control and data acquisition infrastructure to make it compatible with our deployment schemes. Decay data are collected with a 500 kHz sample rate until 25 ms after turn off of the excitation pulse. These data result in a decay of 12,500 points; too many to be used practically. These raw decay measurements are grouped into 122 logarithmically-spaced "gates" with center times ranging from 25 μs to 24.35 ms with 5% widths and are saved to disk.

2.1.2 Application of the Technology

Application of this technology was straightforward. A list of initial target positions was developed from EM61-MK2 data collected by TetraTech in 2012. A plastic pin flag was manually placed over each anomaly location prior to cued data collection. The MP System was then positioned over each target flag in turn. At each position, the transmitter for each array sensor was fired in sequence and decay data were collected from all twelve receiver coils for each transmitter excitation. These data were then stored electronically on the data acquisition computer. Prior to moving to the next target, the operator evaluated the data by running a single-dipole fitting routine to extract target parameters (dipole fit location and magnetic principal polarizability decays). Additionally, the operator reviewed a display of the 4 monostatic, 3-axis signal amplitude decays and transmit current. If the fit location of the anomaly was not sufficiently close to the array center (horizontally) or other data quality metrics were not satisfied (*e.g.* peak signal amplitude), the operator had the option to collect additional data for the target prior to leaving the target location. The EMI data were transferred to the off-site analyst at least once a day for processing and analysis.

2.1.3 Development of the Technology

The MP System is a man-portable four-element transient EMI (TEM) system designed and built by NRL with funding from ESTCP. The MR-200909 project goal was to transition the TEM sensor technology of the TEMTADS towed array (ESTCP Project MR-200601) to a more compact, man-portable configuration for use in more limiting terrain. Preliminary testing of the initial system configuration [4] found that for high SNR (≥ 30) targets one measurement cycle provides enough information to support classification. For deeper and/or weaker targets, more robust estimates of target parameters were obtained by combining two closely-spaced measurements. Two measurements per anomaly were typically made proactively to avoid the potential need to revisit a target a second time. As part of project MR-200909, a demonstration was conducted to rigorously investigate the capabilities of this new sensor platform for unexploded ordnance (UXO) classification in a cued data collection mode at the APG Standardized UXO Test Site in August, 2010 [5]. Those results indicated that the inversion performance of the system was not comparable to that of the full TEMTADS array for lower SNR targets due to the limits of the smaller data set (fewer looks at the target). A modified version of the EMI sensor was designed and built, replacing the single, vertical axis receiver loop of the original coil with a tri-axial receiver cube. These receiver cubes are identical in design to those used in the CRREL MPV2 system (ESTCP MR-201005). The new sensor elements were designed to have the same form factor as the originals, aiding in system fabrication. The completed MP System has been demonstrated as part of the ESTCP Munitions Response Live Site Demonstrations at several sites [6,7,8].

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

The MP System was originally designed to offer similar cued-mode production rates to those seen for larger, vehicular-towed advanced EMI sensors while able to operate in difficult terrain and treed areas that the larger systems cannot access. With the upgraded TEMTADS/3D sensors, similar performance was achieved with similar classification-grade data quality. The MP array is 80 cm on a side and mounted on a man-portable cart. Terrain where the vegetation or topography interferes with passage of a cart of that size will not be amenable to the use of the system. For this demonstration, a litter-mode configuration was successfully demonstrated to alleviate brush-clearing and ground-clearance issues at this site.

There is a limiting anomaly density above which the response of individual targets cannot be separated individually. We have chosen relatively small sensors for this array which help mitigate this problem but we cannot eliminate it completely. Recent developments, including solvers designed for classification in multiple-object scenarios such as SAIC’s multi-target solver, [9] are being evaluated and their performance characteristics in cluttered environments determined.

3.0 PERFORMANCE OBJECTIVES

Performance objectives for the demonstration are given in Table 3-1 to provide a basis for evaluating the performance and costs of the demonstrated technology. Overall project objectives are given in the overall demonstration plan generated by ESTCP. Since this is a classification technology, the performance objectives focus on the second step of the UXO survey problem; we assume that the anomalies from all targets of interest have been detected and included on the target list we worked from. Since the development of the Demonstration Plan Supplement and the Objectives laid out within, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating the objectives, so noted individually, may not become available at a future point.

3.1 OBJECTIVE: REPEATABILTY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

This objective verifies that the sensor system is in good working order and is collecting physically valid data each day. The items emplaced in the Instrument Verification Strip (IVS) were surveyed twice daily. The amplitude of the derived response coefficients and fit location for each emplaced item were compared to the running average of the demonstration for reproducibility.

3.1.1 Metric

The reproducibility of the measured response of the sensor system to the emplaced items defines this metric.

3.1.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients and fit location.

3.1.3 Success Criteria

The objective was considered met if the root-mean-squared (RMS) amplitude variation of the derived response coefficients and fit location were less than 10%.

3.2 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

To collect EMI data of the highest quality for UXO/clutter classification, the anomaly must be illuminated along its three principal axes. To ensure this, the data collection pattern (in this case the TEMTADS array) must be positioned directly over the center of the anomaly.

Table 3-1 – Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
Instrument Verification Strip (IVS) Results	System responds consistently to emplaced items	Daily IVS data	≤ 10% RMS variation in β amplitudes and in fit location
Cued interrogation of anomalies	Instrument position	Cued Data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location
Analysis and Classification Objectives			
Maximize correct classification of TOI	Number of TOI retained	Ranked anomaly lists Results of intrusive investigation	Approach correctly classifies all TOI
Maximize correct classification of non-TOI	Number of false alarms eliminated	Ranked anomaly lists Results of intrusive investigation	Reduction of clutter digs required by >75% while retaining all TOI
Specification of no-dig threshold	Probability of correct classification of TOI and number of false alarms at operating point	Specified threshold Results of intrusive investigation	Threshold specified to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as “Unable to Analyze”	Extracted target parameters	Reliable target parameters can be estimated for > 95% of anomalies.
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Extracted target parameters Results of intrusive investigation	Polarizabilities ± 20% X, Y < 15 cm (1σ) Z < 10 cm (1σ)

3.2.1 Metric

The metric for this objective is the percentage of anomalies that were within the acceptable distance of the center of the instrument during data collection from the actual target location.

3.2.2 Data Requirements

After preliminary data collection and any reacquisition cycles were complete, the offset from array center to inverted target location were determined for each anomaly. The offset distance was required to be less than 40 cm.

3.2.3 Success Criteria

The objective was considered met if the center of the instrument was positioned within 40 cm of the anomaly fit location for 100% of the cued anomalies. Exceptions were made for anomalies which were partially or completely occluded by obstructions such as trees or were located in areas where intrusive investigation were not planned (*e.g.* roads). Several earthen berms formed from bulldozed dirt, vegetation, and MEC were also excluded from the demonstration for not being good candidates for classification. Anomalies located within a known test plot were also excluded at the request of site personnel.

3.3 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

This is one of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms we should be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves correct classification of TOI. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

3.3.1 Metric

The metric for this objective is the number of items on the MP System anomaly list that were correctly classified as TOI.

3.3.2 Data Requirements

A ranked anomaly list was prepared for the targets on the MP System anomaly list.

3.3.3 Success Criteria

For the purposes of this demonstration, the objective was considered met if all of the TOI were correctly labeled as TOI on the ranked anomaly list. This is a more stringent criterion than required for the site clean-up objectives listed in the Source Removal Work Plan. It was possible

to achieve results adequate for the site-specific cleanup objectives but below the 100% correct classification specified.

3.4 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This is the second of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms we expect to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

3.4.1 Metric

The metric for this objective is the number of items on the MP System anomaly list that were correctly classified as non-TOI.

3.4.2 Data Requirements

A ranked anomaly list was prepared for the targets on the MP System anomaly list.

3.4.3 Success Criteria

The objective was considered met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI on the dig list.

3.5 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis as was performed in this demonstration, it is possible to tell the true classification capabilities of a classification procedure based solely on the ranked anomaly list submitted. In a real-world scenario, all targets may not be dug so the success of the approach will depend on the ability of an analyst to accurately specify their dig/no-dig threshold. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

3.5.1 Metric

The probability of correct classification of TOI, P_{class}, and number of false alarms, N_{fa}, at the demonstrator-specified threshold were the metrics for this objective.

3.5.2 Data Requirements

A ranked anomaly list with a dig/no-dig threshold indicated was prepared for the MP System anomaly list.

3.5.3 Success Criteria

The objective was considered met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI at the demonstrator-specified threshold.

3.6 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Evaluation of anomalies for which reliable parameters could not be estimated cannot continue in the classification analysis pipeline. These anomalies must be placed in the dig category and reduce the effectiveness of the classification process.

3.6.1 Metric

The number of anomalies for which reliable parameters could not be estimated was the metric for this objective.

3.6.2 Data Requirements

A list of all extracted target parameters was provided as part of the results submission along with a list of those anomalies for which parameters could not be reliably estimated.

3.6.3 Success Criteria

The objective was considered met if reliable parameters were estimated for > 95% of the anomalies on the anomaly list.

3.7 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that were estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

3.7.1 Metric

Accuracy of estimation of target parameters was the metric for this objective.

3.7.2 Data Requirements

The estimated parameters for the seed items and the ground truth for the seed items are required data.

3.7.3 Success Criteria

The objective was considered met if the estimated polarizabilities were within ± 20%, the estimated X, Y locations were within 15 cm (1σ), and the estimated depths were within 10 cm (1σ).

4.0 SITE DESCRIPTION

Please refer to the ESTCP Live Site Demonstrations Plan for the MMR CIA [1].

4.1 GPS CONTROL POINTS

There is one permanent, fixed GPS station operational with coverage of the CIA, named "Pine Hill Reset." The station is located near Range Control on a hilltop. This station was used as the GPS base station for the 2012 demonstration. Parsons, as part of the demonstration seeding effort, used this station to establish two additional control points in the direct vicinity of the MetalMapper sub-area and the 2012 IVS location. The fixed station uses a different radio configuration that we do and had to be altered in 2012 to communicate with our GPS equipment. Rather than interfere with ongoing operations onsite, we used the "Parsons Base" auxiliary control points, whose accuracy was verified during Parsons seeding and MetalMapper demonstration efforts, for the 2013 demonstration. The details of the three base station points are listed in Table 4-1.

Table 4-1 – GPS Control Points in or near the MMR CIA

ID	Easting (m)	Northing (m)	Latitude (deg)	Longitude (deg)	HAE (m)
Pine Hill Reset	369,733.893	4,618,606.567	41º 42' 30.92393"	-70º 33' 56.81178"	51.270
Parsons Base	372,075.871	4,618,769.323	41º 42' 37.56772"	-70º 32' 15.63205"	50.028
QC Pipe Parsons	372,067.165	4,618,744.806	41º 42' 36.76799"	-70º 32' 15.98970"	49.039

[a] Easting and Northing are expressed in UTM Zone 19N (meters)
[b] All horizontal locations are in the NAD83 datum

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The demonstration was executed in two stages. The first stage characterized the MP System with respect to the site-specific geology. The background response of the demonstration site, as measured by the MP System, was characterized throughout the data collection process.

The second stage of the demonstration was the cued survey of the remaining fraction of the Man-Portable subarea of the demonstration site using the MP System. The array was positioned roughly over the center of each target flag and a data set collected. Each data set was inverted using the data analysis methodology discussed in Section 6.0, and estimated target parameters determined. The results and the archive data were submitted to the Program Office. Using the fit results, a prioritized dig list was prepared and submitted to the Program Office.

The schedule of field testing activities is provided in Figure 5-1 as a Gantt chart.

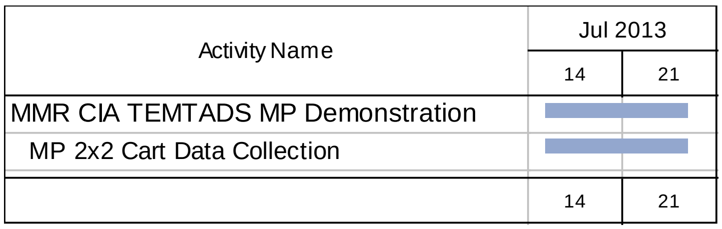

Figure 5-1 – Schedule of Field Testing Activities

5.2 SITE PREPARATION

Please refer to the ESTCP Live Site Demonstrations Plan for the MMR CIA [1].

An Instrument Verification Strip (IVS) was emplaced by Parsons for the 2012 demonstration season and subsequently removed. TetraTech emplaced a new IVS which was available for the 2013 demonstration. The details of the IVS are given in Table 5-1.

Table 5-1 – Details of the TetraTech 2013 Central Impact Area IVS

ID	Description	Easting (m)	Northing (m)	Depth (m)	Inclination	Orientation
T-01	155mm Projectile	372,039.889	4,618,975.979	0.23	Horizontal	Along Track
T-02	105mm Projectile	372,037.379	4,618,977.423	0.20	Horizontal	Along Track
T-03	Medium ISO #1	372,043.516	4,618,977.582	0.18	Horizontal	Along Track
T-04	Medium ISO #2	372,043.782	4,618,975.526	0.18	Horizontal	Along Track

[a] Easting and Northing are expressed in UTM Zone 19N (meters).

[b] Depth is reported to center of the items and is calculated based on a stated burial to 15 cm for the top of each item and nominal diameter of each item.

5.3 SYSTEMS SPECIFICATION

This demonstration was conducted using the NRL TEMTADS MP 2x2 Cart.

5.3.1 TEMTADS MP 2x2 Cart

The MP System is a man-portable system comprised of four of the TEMTADS/3D EMI sensors discussed in Section 2.1.1 arranged in a 2x2 array as shown in Figure 5-2. The direction of travel is to the left in Figure 5-2 (left) and up in Figure 5-2 (right). The MP System, shown in

Figure 5-3 (left) at Fort Rucker, AL, is fabricated from PVC plastic and fiberglass. The center-to-center distance is 40 cm yielding an 80 cm x 80 cm array. The array is deployed on a set of wheels resulting in a sensor-to-ground offset of approximately 20 cm. The transmitter electronics and the data acquisition computer are mounted in the operator backpack, as shown in Figure 5-5. The MP System can be operated in two modes; dynamic or survey mode and cued mode. A Global Positioning System (GPS) receiver and an inertial measurement unit (IMU) are mounted above the TEM array as shown in Figure 5-3 (right). Data collection is controlled in dynamic mode using G&G Science's EM3D application suite, the same software that used for the Geometrics MetalMapper systems. In cued mode, the locations of the anomalies must already be known and flagged for reacquisition. Custom software written by NRL provides cued data acquisition functionality.

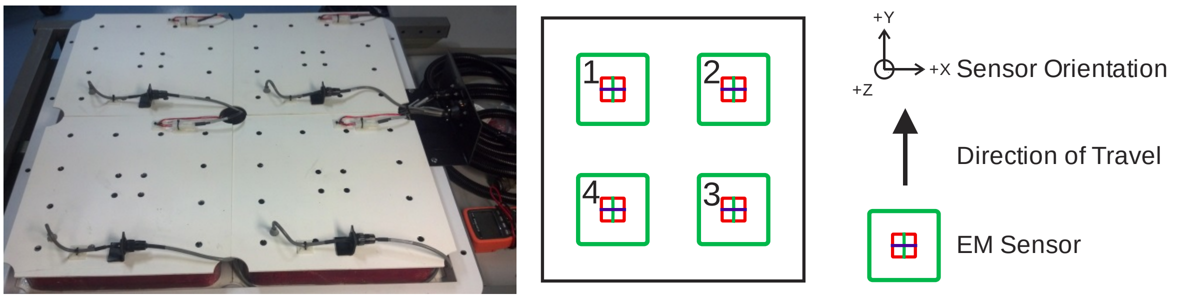

Figure 5-2 – TEMTADS/3D EMI sensor array with weather cover removed (left). Sketch of the EMI sensor array showing the position of the four sensors. The tri-axial, revised EMI sensors are shown schematically (right). The direction of travel for the array and the orientation of the sensor cubes are indicated.

In cued mode, the operators position the cart over each anomaly location in turn and collect a set of TEM data. Geolocation and cart orientation are monitored and recorded. Functionality to record field notes is provided. If anomaly flagging is unavailable or undesirable, it is possible to load a list of virtual flag locations into the vendor-provided survey controller for the GPS unit and use the provided interface for anomaly-to-anomaly navigation. This has been tested using a Trimble R8 GNSS version 3 GPS receiver and a TSC2 survey controller.

Figure 5-3 – The NRL TEMTADS Man-Portable 2x2 Cart (left) and TEMTADS MP 2x2 Cart with GPS Antenna Tripod (right)

Due to the terrain and the state of brush clearance in the work area, a litter-carry configuration was used to carry the system from flag to flag, as shown in Figure 5-4. While significantly easier to navigate the site with than the wheeled version, the additional weight and complexity of the litter-carry configuration necessitates a third operator.

5.3.2 Data Acquisition User Interface

The data acquisition computer is mounted on a backpack worn by one of data acquisition operators, shown in Figure 5-5 (left). The second operator controls the data collection using a tablet computer which wirelessly (IEEE 802.11g) communicates with the data acquisition computer. The second operator also manages field notes and team orienteering functions. In Figure 5-3 (left) and Figure 5-4 (right), a data collection team is shown in action.

Figure 5-4 – The NRL TEMTADS Man-Portable 2x2 Litter-Carry Configuration (left) and the Litter-Carry Configuration at MMR in 2013 (right)

The tablet PC user interface is shown in Figure 5-5 (right). In litter-carry mode, a third person lifts and carries the front of the system.

Figure 5-5 – (left) TEMTADS 2x2 Electronics Backpack, (right) Screenshot of Tablet Computer Interface

5.4 CALIBRATION ACTIVITIES

5.4.1 TEMTADS Sensor Calibration

For the TEMTADS family of platforms, a significant amount of data has been collected with the systems as configured at our Blossom Point facility, both on test stands, on our test field [10] and at APG [11], and as part of the ESTCP Live Site Demonstrations, [6,8,12-14], and at MMR [7]. These data and the corresponding fit parameters provide us with a set of reference parameters including those of clear background (i.e. no anomaly present).

Daily calibration efforts consisted of collecting background (no anomaly) data sets periodically throughout the day at quiet spots to determine the intra-site variation in system response to the local geology and to monitor the system noise floor. The items emplaced in the IVS were measured twice daily to monitor the variation in the system response. Variations were expected to be within 10% of the reference values. These two types of measurements constituted the daily calibration activities.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Scale of Demonstration

NRL and NAEVA Geophysics conducted a cued classification survey on the remaining 1.75 acres of the 3-acre man-portable subarea selected from within the 330-acre CIA demonstration site. The 2012 NRL survey investigated 1,005 anomalies in the northern 1.25 acres of the man-portable area. Cued data collection was conducted for the remaining 1,429 anomalies previously identified from an EM61-MK2 cart survey conducted in 2012 by National Guard Bureau contractor TetraTech. This survey used the MP System in a litter-carry configuration. Characterization of the system responses to the Targets of Interest (TOIs) was based on previously acquired TEMTADS reference data. These data were collected in accordance with the overall study objectives and demonstration plan. Unlike the 2012 demonstration, classification analysis of the interrogated anomalies was also conducted. As part of the demonstration, plastic pin flags were installed at each target location on the source list prior to data collection. Performance of the system response was determined on a twice-daily basis using the onsite IVS. The data segment (chip) for each anomaly was analyzed, and dipole model fit parameters extracted. These results were provided to the ESTCP Program Office in addition to the archival data. Using these results, a prioritized dig list was prepared and submitted to the ESTCP Program Office for scoring.

5.5.2 Sample Density

The EMI data spacing for the TEMTADS is fixed at 40 cm in both directions by the array design.

5.5.3 Quality Checks

Preventative maintenance inspections were conducted at least once a day by all team members, focusing particularly on the litter-carry structure and the cabling. Any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for many maintenance scenarios were available in the system spares inventory which was located on site. Status on any break-downs / failures which would result in long-term delays in operations would have been immediately reported to the ESTCP Program Office. None occurred.

The GPS data QC procedures and checks were as follows. The status of the RTK GPS system was visually determined by the operator prior to starting the data collection cycle, assuring that the position information were valid during the collection period, with Fix Quality (FQ) 3 for the *GGK* NMEA sentence. A Fix Quality (FQ) value of 3 (RTK Fixed) is the best accuracy (typically 3-5 cm or better). A FQ value of 2 (RTK Float) indicates that the highest level of RTK has not be reached yet and location accuracy can be degraded to as poor as ~1 m. FQs 1 & 4 correspond to the Autonomous and DGPS operational modes, respectively. Data collected under FQ 3 and FQ 2 (at the discretion of the data analyst) are retained. The *GGA* NMEA sentence output from the receiver was used for this demonstration, and the FQ values are different (*i.e.* FQ 4 = Fixed), but the process is the same.

Two data quality checks were performed on the cued EMI data. After background subtraction, plots were made of the 48 transmitter / receiver pairs. An example plot is shown in Figure 5-6 for a horizontal 3” diameter x 12” long solid steel cylinder at a depth of 45 cm below the sensor array. The plots were visually inspected to verify that there was a well-defined anomaly without extraneous signals or dropouts. QC on the transmit/receive cross terms was based on the dipole inversion results. Our experience has been that data glitches are observed as reduced dipole fit coherence.

In cued mode, the operator had access to a series of monostatic decay plots to allow for on-the-fly data QC. An example monostatic decay plot for a high SNR anomaly centered under the array is shown in Figure 5-7.

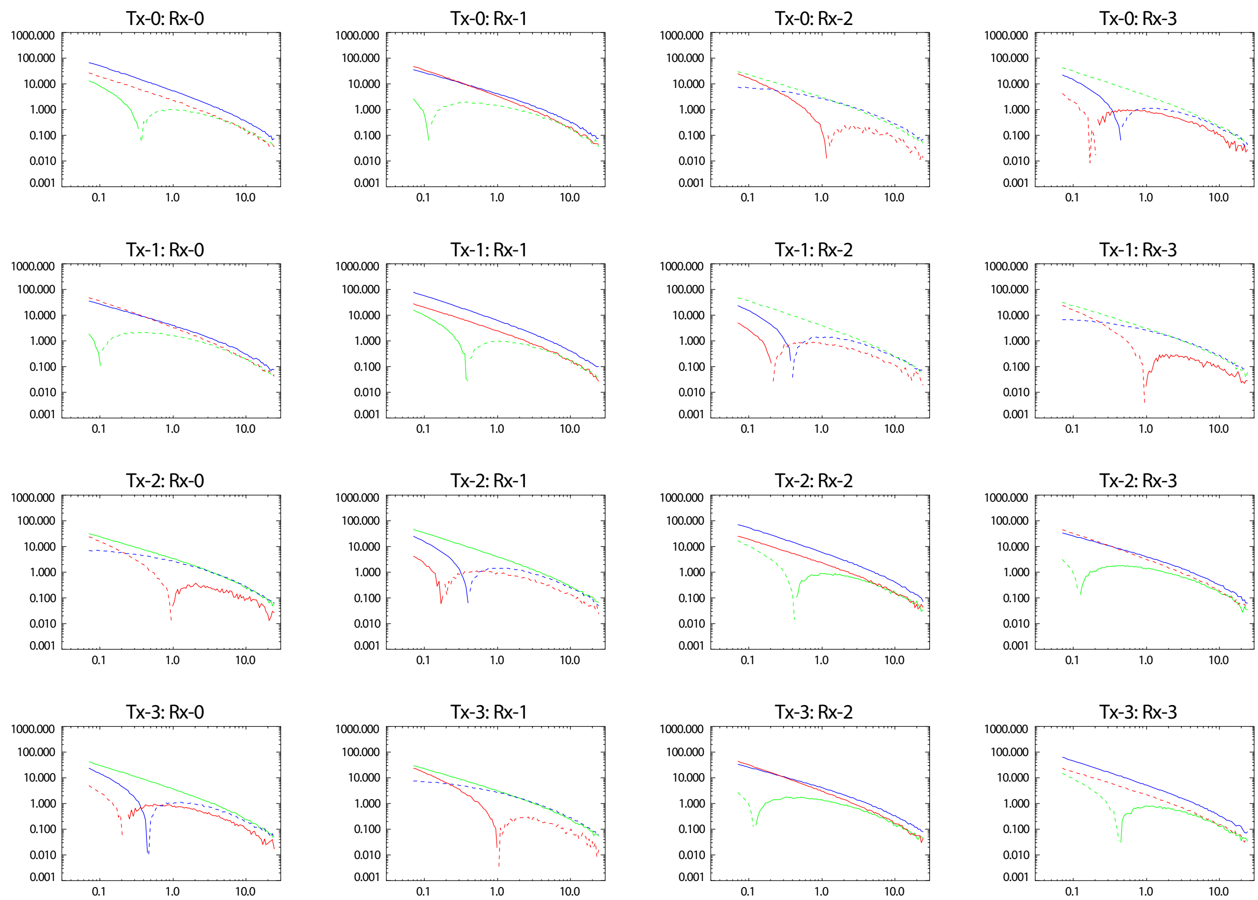

Figure 5-6 – QC Plot for a 3” x 12” solid steel cylinder, horizontal at a depth of 45cm below the sensors. The z,y,x-components in each subplot are shown in blue, green, and red, respectively.

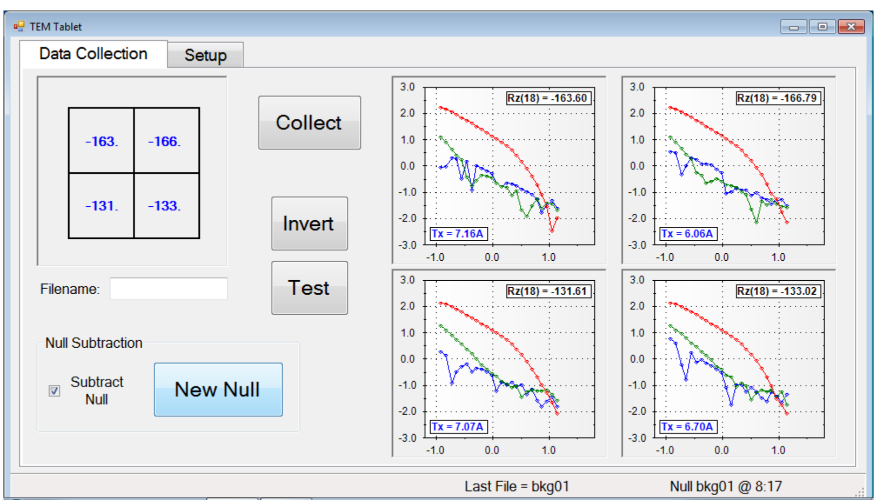

Figure 5-7 – Screenshot of the Operator Tablet Decay Transient Display. A large object centered under the array is indicated.

Any data set deemed unsatisfactory by the data analyst was flagged and not processed further. The anomaly corresponding to the flagged data was logged for future re-acquisition. Data which met these standards were of the quality typical of the TEMTADS system.

5.5.4 Data Handling

Data were stored electronically as collected on the backpack data acquisition computer hard drive. At least once daily, the data were transferred to the off-site data analyst for QC/analysis. Raw data and analysis results are backed up from the data analyst's computer to external hard disks daily. These results are archived on an internal file server at NRL at the end of the survey. Examples of the TEMTADS file formats are provided in Appendix C. All field notes / activity logs were written in ink and stored in archival laboratory notebooks. These notebooks were archived at NRL or NAEVA. Relevant sections were reproduced in documents such as this demonstration data report. Dr. Daniel Steinhurst is the Point of Contact (POC) for obtaining data and other information. His contact information is provided in Appendix B of this report.

5.6 VALIDATION

Typically, at the conclusion of an ESTCP Project Live Site Demonstration, some or all anomalies would be excavated. Each item encountered would be identified, photographed, its depth below grade measured, its location determined using cm-level GPS, and the item removed if possible. This ground truth information would then be used to validate the objectives listed in Section 3.0. Since the development of the Demonstration Plan Supplement and the Objectives laid out within, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report.

6.0 DATA ANALYSIS PLAN

6.1 PREPROCESSING

The MP System has four sensor elements, each comprised of a transmitter coil and a tri-axial receiver cube. For each transmit pulse, the responses at all of the receivers are recorded. This results in 48 possible transmitter / receiver combinations in the data set (4 transmitters x 4 receiver cubes x 3 receiver axes). Although the data acquisition system records the signal over 122 logarithmically-spaced time gates starting at 25 μs, the measured responses over the first 17 gates included distortions due to transmitter ringing and related artifacts and are discarded. We further subtract 0.028 ms from the nominal gate times to account for time delay due to effects of the receive coil and electronics [15]. The delay was determined empirically by comparing measured responses for test spheres with theory. This leaves 105 gates spaced logarithmically between 0.089 ms and 24.35 ms. In preprocessing, the recorded signals are normalized by the peak transmitter current to account for any variation in the transmitter output. On average, the peak transmitter current is approximately 6.5 Amps.

The background response is subtracted from each target measurement using data collected at a nearby target-free background location. The background measurements are reviewed for variability and to identify outliers, which may correspond to measurements over targets. In previous testing at our Blossom Point test field and during other demonstrations, significant background variability was not observed. It has been possible to use blank ground measurements from 100 meters away for background subtraction. Changes in moisture content and outside temperature have been shown to cause variation in the backgrounds, necessitating care when collecting data after weather events such as rain.

6.2 PARAMETER ESTIMATION

The raw signature data from the TEMTADS sensors reflect details of the sensor/target geometry as well as inherent EMI response characteristics of the targets themselves. In order to separate out the intrinsic target response properties from sensor/target geometry effects, we inverted the signature data to estimate principal axis magnetic polarizabilities for the targets. The TEMTADS data were inverted using the standard induced dipole response model wherein the effect of eddy currents set up in the target by the primary field is represented by a set of three orthogonal magnetic dipoles at the target location [16]. The measured signal is a linear function of the induced dipole moment **m**, which can be expressed in terms of a time dependent polarizability tensor **B** as

$$\mathbf{m} = \mathbf{U}\mathbf{B}\mathbf{U}^{T}\cdot\mathbf{H}_0$$

where **U** is the transformation matrix between the physical coordinate directions and the principal axes of the target and $\mathbf{H}_0$ is the primary field strength at the target. The eigenvalues $\beta_i(t)$ of the polarizability tensor are the principal axis polarizabilities.

Given a set of measurements of the target response with varying geometries or "look angles" at the target, the data can be inverted to determine the local (X,Y,Z) location of the target, the orientation of its principal axes (ϕ,θ,ψ), and the principal axis polarizabilities (β_1,β_2,β_3). The basic idea is to search out the set of nine parameters ($X,Y,Z,\phi,\theta,\psi,\beta_1,\beta_2,\beta_3$) that minimizes the difference between the measured responses and those calculated using the dipole response model. The location and orientation information recorded from the GPS and IMU are then used to locate the fit results in three-dimensional space.

For TEMTADS data, inversion is accomplished by a two-stage method. In the first stage, the target's (X,Y,Z) dipole location beneath are solved for non-linearly. At each iteration within this inversion, the nine element polarizability tensor (**B**) is solved linearly. We require that this tensor be symmetric; therefore, only six elements are unique. Initial guesses for X and Y are determined by a signal-weighted mean. The routine normally loops over a number of initial guesses in Z, keeping the result giving the best fit as measured by the chi-squared value. The non-linear inversion is done simultaneously over all time gates, such that the dipole (X,Y,Z) location applies to all decay times. At each time gate, the eigenvalues and angles are extracted from the polarizability tensor.

In the second stage, six parameters are used: the three spatial parameters (X,Y,Z) and three angles representing the yaw, pitch, and roll of the target (Euler angles ϕ,θ,ψ). Here the eigenvalues of the polarizability tensor are solved for linearly within the 6-parameter non-linear inversion. In this second stage both the target location and its orientation are required to remain constant over all time gates. The value of the best fit X,Y,Z from the first stage, and the median value of the first-stage angles are used as an initial guess for this stage. Additional loops over depth and angles are included to better ensure finding the global minimum.

Figure 6-1 shows an example of the principal axis polarizabilities determined from TEMTADS array data. The target, a mortar fragment, is a slightly bent plate about ½ cm thick, 25 cm long, and 15 cm wide. The red curve is the polarizability when the primary field is normal to the surface of the plate, while the green and blue curves correspond to cases where the primary field is aligned along each of the edges.

Not every target on the target list had a strong enough TEM response to support extraction of target polarizabilities. All of the data were run through the inversion routines, and the results were manually screened to identify those targets that could not be reliably parameterized. Several criteria were used in this process: signal strength relative to background, dipole fit error (difference between data and model fit to data), and the visual appearance of the polarizability curves.

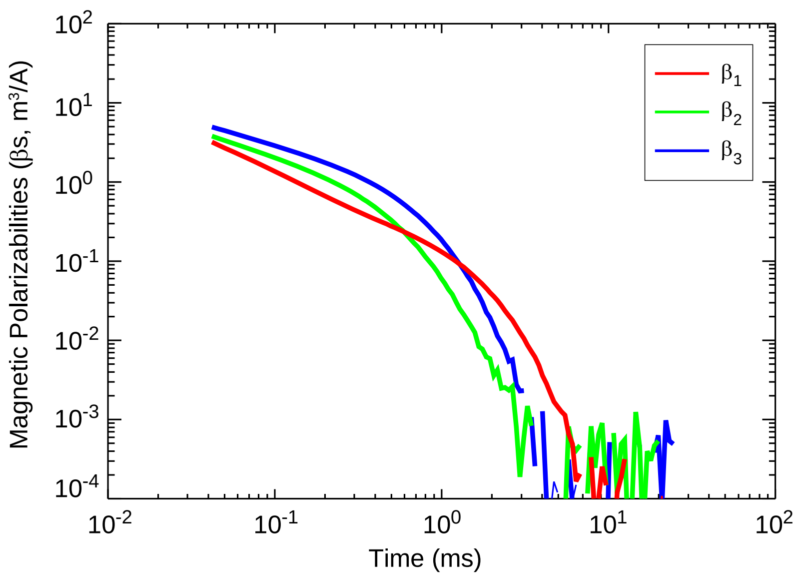

Figure 6-1 – Principal axis polarizabilities for a 0.5 cm thick by 25cm long by 15cm wide mortar fragment.

6.3 CLASSIFIER AND TRAINING

Target classification was based on a library matching procedure wherein we compared the results of a dipole inversion of the TEM array data to principal axis polarizabilities drawn from a library of known signatures. The match to a library entry is based on three criteria: the amplitude of the primary polarizability, and the ratio of the second and third polarizabilities to the first. Multiple metrics, each of which run from 0 (terrible match) to 1 (perfect match), are used to evaluate each match.

Our experience with these sensors has been that principal polarizabilities determined from in-air measurements are indistinguishable from those determined from measurements taken over buried targets. We have an extensive collection of inert military munitions collected from many sources which were measured at our home facility using the TEMTADS family of sensors mounted on a test stand. We have also assembled a fairly extensive polarizability database for clutter items recovered from several different live sites. These data collections were used as training data for establishing UXO/clutter discrimination boundaries on the library match metrics.

6.4 DATA PRODUCT SPECIFICATIONS

For all anomalies and IVS measurements, the deliverables for this demonstration were the raw data files, background-subtracted data files, and fit results. A prioritized dig list for all anomalies was also provided. All deliverables were submitted to the ESTCP Program Office. See Appendix C for the detailed data product specifications.

7.0 PERFORMANCE RESULTS

The performance objectives for the demonstration were given in Table 3-1 and are repeated here in Table 7-1 and Table 7-4. The results for each criterion are subsequently discussed in the following sections. Since the development of the Demonstration Plan Supplement and the Objectives laid out within, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating the demonstration performance, so noted individually, may not become available at a future point.

Table 7-1 – Data Collection Performance Results for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success? (Yes/No)
Data Collection Objectives				
Instrument Verification Strip (IVS) Results	System responds consistently to emplaced items	Daily IVS data	≤ 10% RMS variation in β amplitudes and in fit location	Yes
Cued interrogation of anomalies	Instrument position	Cued Data	100% of anomalies where the center of the instrument is positioned within 40 cm of actual target location	Yes

7.1 OBJECTIVE: REPEATABILTY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

This objective verifies that the sensor system is in good working order and is collecting physically valid data each day. The items emplaced in the Instrument Verification Strip (IVS) were surveyed twice daily. The amplitude of the derived response coefficients and fit location for each emplaced item were compared to the running average of the demonstration for reproducibility.

7.1.1 Metric

The reproducibility of the measured response of the sensor system to the emplaced items defines this metric.

7.1.2 Data Requirements

The tabulated fit parameters for the data corresponding to each emplaced item in terms of derived response coefficients and fit location.

7.1.3 Success Criteria

The objective was considered met if the root-mean-squared (RMS) amplitude variation of the derived response coefficients and fit location were less than 10%.

7.1.4 Results

This objective is considered a success. Each emplaced item in the IVS was measured twice daily, once before starting the data collection process and a second time before shutting the system down at the end of each day. Details of the contents of the CIA IVS are given in Table 5-1. A background spot was not provided in the IVS. One was found nearby using the MP System in concert with a handheld magnetometer.

All data sets for each of the emplaced IVS items were inverted using the data analysis methodology discussed in Section 6.0, and the estimated target parameters determined. Geolocation and sensor platform orientation are now available for the MP System in cued mode, unlike previous demonstrations of the MP System.

The results for the seventeen cued mode IVS measurements are given in Table 7-2 and shown in Figure 7-1. The RMS variation in the magnetic polarizability amplitudes at 0.089 ms were less than 4% for all three magnetic polarizabilities. The aggregate position and depth error statistics for the IVS items are listed in Table 7-3 and shown in Figure 7-2. The position error is defined as the fit position (or, equivalently, the inverted position parameter) minus the position given in Table 5-1. The RMS variation in the position errors for each emplaced IVS item was under 2 cm. Depth error is expressed as the difference between the fitted depth and the listed emplacement depth.

The RMS variation in the depth errors for each emplaced IVS item was 0.23 cm (1%) or less. The location and depth of the IVS items could not be independently verified by our team. In the case of the depth, the value is calculated from several provided pieces of information as noted in Table 5-1. Discussion of any mean offsets would require detailed recovery of the items.

Table 7-2 –Summary of the Amplitude Variations at 0.089 ms in the Derived Response Coefficients for All Items Emplaced in the IVS.

Item	β_1 Amplitude (m^3)				β_2 Amplitude (m^3)				β_3 Amplitude (m^3)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
155mmP	58.04	64.28	60.89	1.730	55.33	58.99	57.54	1.042	48.95	53.08	51.73	1.110
105mmP	23.74	26.59	24.84	0.779	19.89	21.37	20.60	0.379	18.59	20.07	19.25	0.386
Med. ISO #1	8.56	9.08	8.74	0.152	5.13	5.48	5.34	0.097	4.67	4.87	4.76	0.056
Med. ISO #2	9.32	10.36	9.82	0.299	5.54	6.25	5.83	0.224	5.11	5.41	5.25	0.097

Table 7-3 – Summary of Position and Depth Error Statistics for all items emplaced in the IVS.

Item	Easting Position Error (cm)				Northing Position Error (cm)				Depth Error (cm)			
	Min	Max	Mean	RMS	Min	Max	Mean	RMS	Min	Max	Mean	RMS
155mmP	1.84	9.05	5.41	1.88	-3.40	2.10	-0.29	1.317	-8.52	-7.97	-8.13	0.15
105mmP	-3.54	1.45	-1.57	1.67	-4.50	1.10	-1.46	1.396	-7.19	-6.62	-6.86	0.18
Med. ISO #1	-1.82	3.69	-0.04	1.30	-4.40	2.40	0.04	1.692	-6.79	-5.97	-6.25	0.20
Med. ISO #2	1.32	6.72	4.62	1.18	-5.70	-0.10	-3.31	1.46	-7.69	-6.96	-7.26	0.23

Table 7-4 – Analysis and Classification Performance Results for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria	Success? (Yes/No)
Analysis and Classification Objectives				
Maximize correct classification of TOI	Number of TOI retained	Ranked anomaly lists Results of intrusive investigation	Approach correctly classifies all TOI	Not Evaluated
Maximize correct classification of non-TOI	Number of false alarms eliminated	Ranked anomaly lists Results of intrusive investigation	Reduction of clutter digs required by >75% while retaining all TOI	Not Evaluated
Specification of no-dig threshold	Probability of correct classification of TOI and number of false alarms at operating point	Specified threshold Results of intrusive investigation	Threshold specified to achieve criteria above	Not Evaluated
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as "Unable to Analyze"	Extracted target parameters	Reliable target parameters can be estimated for > 95% of anomalies	Yes
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Extracted target parameters Results of intrusive investigation	Polarizabilities ± 20% X, Y < 15 cm (1σ) Z < 10 cm (1σ)	Not Evaluated

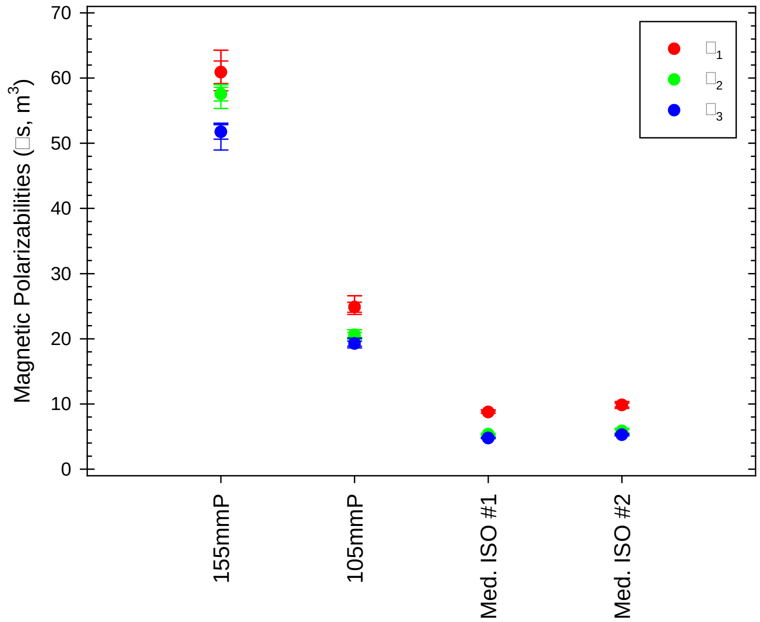

Figure 7-1 – Amplitude variations at 0.089 ms in the derived response coefficients for all items emplaced in the IVS. β_1 is in red; β_2 is in green; and β_3 is in blue.

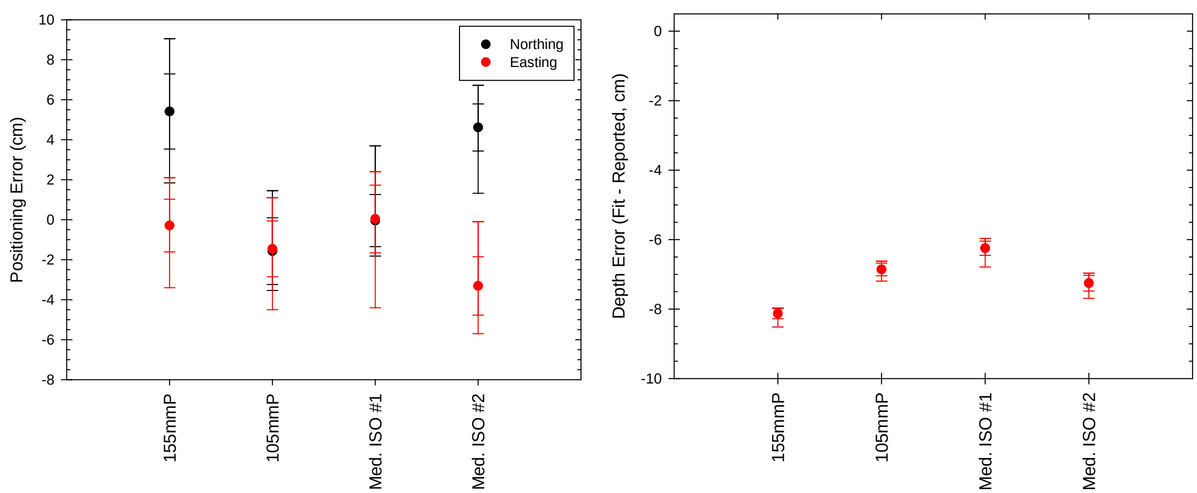

Figure 7-2 – Position error statistics for the four items emplaced in the IVS (left panel). Easting data are in black and Northing data are in red. Depth error statistics for the same items (right panel).

7.2 OBJECTIVE: CUED INTERROGATION OF ANOMALIES

To collect EMI data of the highest quality for UXO/clutter classification, the anomaly must be illuminated along its three principal axes. To ensure this, the data collection pattern (in this case the TEMTADS array) must be positioned directly over the center of the anomaly.

7.2.1 Metric

The metric for this objective is the percentage of anomalies that were within the acceptable distance of the center of the instrument during data collection from the actual target location.

7.2.2 Data Requirements

After preliminary data collection and any reacquisition cycles were complete, the offset from array center to inverted target location were determined for each anomaly. The offset distance was required to be less than 40 cm.

7.2.3 Success Criteria

The objective was considered met if the center of the instrument was positioned within 40 cm of the anomaly fit location for 100% of the cued anomalies. Exceptions were made for anomalies which were partially or completely occluded by obstructions such as trees or were located in areas where intrusive investigation were not planned (*e.g.* roads). Several earthen berms formed from bulldozed dirt, vegetation, and MEC were also excluded from the demonstration for not being good candidates for classification. Anomalies located within a known test plot were also excluded at the request of site personnel.

7.2.4 Results

A finalized dig list, including fit results from both single- and multi-dipole solvers, was available as of August 26, 2013. Based on the finalized fit results, the offset from the array center to the fit location of each classified target was calculated. All offsets were less than or equal to 40 cm except for three targets. For flag CE-3580, the fit result source was the same location as the result for nearby flag CE-3569. This was interpreted to indicate no source at the position of flag CE-3580. The remaining two flags, CE-4009 and CE-4101 appeared to be from a large source located outside the survey area boundary and were classified as “cannot analyze.” This Objective is considered successful.

7.3 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

This is one of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms, we should be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves correct classification of TOI. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

7.3.1 Metric

The metric for this objective is the number of items on the MP System anomaly list that were correctly classified as TOI.

7.3.2 Data Requirements

A ranked anomaly list was prepared for the targets on the MP System anomaly list.

7.3.3 Success Criteria

For the purposes of this demonstration, the objective was considered met if all of the TOI were correctly labeled as TOI on the ranked anomaly list. This is a more stringent criterion than required for the site clean-up objectives listed in the Source Removal Work Plan. It was possible to achieve results adequate for the site-specific cleanup objectives but below the 100% correct classification specified.

7.3.4 Results

The data for determining the success of this objective are not currently available, and may not become available in the future. If the data become available, the analysis can be revisited.

7.4 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This is the second of the two primary measures of the effectiveness of the classification approach. By collecting high-quality data and analyzing those data with advanced parameter estimation and classification algorithms we expect to be able to classify the targets with high efficiency. This objective concerns the component of the classification problem that involves false alarm reduction. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

7.4.1 Metric

The metric for this objective is the number of items on the MP System anomaly list that were correctly classified as non-TOI.

7.4.2 Data Requirements

A ranked anomaly list was prepared for the targets on the MP System anomaly list.

7.4.3 Success Criteria

The objective was considered met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI on the dig list.

7.4.4 Results

The data for determining the success of this objective are not currently available, and may not become available in the future. If the data become available, the analysis can be revisited.

7.5 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis as was intended for this demonstration, it is possible to tell the true classification capabilities of a classification procedure based solely on the ranked anomaly list submitted. In a real-world scenario, all targets may not be dug so the success of the approach will depend on the ability of an analyst to accurately specify their dig/no-dig threshold. Since the development of this objective as part of the Demonstration Plan Supplement, events have transpired such that dig results may not become available to allow for scoring the classification results presented in this report. As such, the requisite data for evaluating this objective may not become available at a future point.

7.5.1 Metric

The probability of correct classification of TOI, P_{class}, and number of false alarms, N_{fa}, at the demonstrator-specified threshold were the metrics for this objective.

7.5.2 Data Requirements

A ranked anomaly list with a dig/no-dig threshold indicated was prepared for the MP System anomaly list.

7.5.3 Success Criteria

The objective was considered met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI at the demonstrator-specified threshold.

7.5.4 Results

The data for determining the success of this objective are not currently available, and may not become available in the future. If the data become available, the analysis can be revisited.

7.6 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Evaluation of anomalies for which reliable parameters could not be estimated cannot continue in the classifier analysis pipeline. These anomalies must be placed in the dig category and reduce the effectiveness of the classification process.

7.6.1 Metric

The number of anomalies for which reliable parameters could not be estimated was the metric for this objective.

7.6.2 Data Requirements

A list of all extracted target parameters was provided as part of the results submission along with a list of those anomalies for which parameters could not be reliably estimated.

7.6.3 Success Criteria

The objective was considered met if reliable parameters were estimated for > 95% of the anomalies on the anomaly list.

7.6.4 Results

This Objective is considered successful. Of the 1,429 remaining flag locations, 1,291 were accessible for measurement and not located in areas that were considered 'out-of-bounds,' such as the roads and a test area located within the survey area. Of the 1,291 flags investigated, data were collected from which reliable fit parameters could be extracted for all but five flag locations (99.4%).

7.7 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that were estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

7.7.1 Metric

Accuracy of estimation of target parameters was the metric for this objective.

7.7.2 Data Requirements

The estimated parameters for the seed items and the ground truth for the seed items are required data.

7.7.3 Success Criteria

The objective was considered met if the estimated polarizabilities were within ± 20%, the estimated X, Y locations were within 15 cm (1σ), and the estimated depths were within 10 cm (1σ).

7.7.4 Results

The data for determining the success of this objective are not currently available, and may not become available in the future. If the data become available, the analysis can be revisited.

7.8 BACKGROUND SIGNAL VARIATION RESULTS

A group of anomaly-free areas along the road bisecting the ManPortable subarea were identified in advance from the EM61-MK2 data set and by inspection with a hand-held magnetometer. An example of a background measurement being made is shown in Figure 7-3. Each background location was confirmed to be anomaly-free prior to prolonged use with the MP System. Any location found to exhibit an anomaly was discarded and not used further. Since the viable locations all provided roughly comparable responses, a convenient subset of the locations was chosen to be visited periodically throughout each day of the demonstration. All 67 field background measurements taken for the duration of the survey are shown in Figure 7-4, and are presented as the mean and standard deviation of the four monostatic measured signals. Dates are presented as Julian dates, or the day of the year. July 15, 2013 is Julian date 196. Table 7-5 tabulates the intraday variations of the mean and standard deviation quantities from Figure 7-4. Additional background measurements were made near the IVS but are not included here.

Figure 7-3 – Team Members Preparing for a Background Measurement

Table 7-5 – Summary of the Daily Variation in the Mean and Standard Deviation of the Signals Measured for the MP System Background Areas.

Date	# of Bkgs.	Mean Z (mV/Amp)	Std. Dev. Z (mV/Amp)	Mean Y (mV/Amp)	Std. Dev. Y (mV/Amp)	Mean X (mV/Amp)	Std. Dev. X (mV/A)
7/15/2013	4	29.61	0.86	1.08	0.58	1.41	0.51
7/16/2013	6	29.66	0.60	1.29	0.45	1.53	0.49
7/17/2013	9	28.03	1.09	1.13	0.52	1.54	0.64
7/18/2013	12	29.72	0.48	1.00	0.42	1.38	0.48
7/20/2013	10	28.10	0.66	1.04	0.70	1.32	0.37
7/21/2013	8	28.09	0.59	0.97	0.57	1.42	0.46
7/22/2013	10	27.19	0.80	0.99	0.44	1.21	0.55
7/23/2013	4	27.04	0.57	0.82	0.42	1.18	0.48
7/24/2013	4	26.87	0.87	1.12	0.62	1.35	0.53

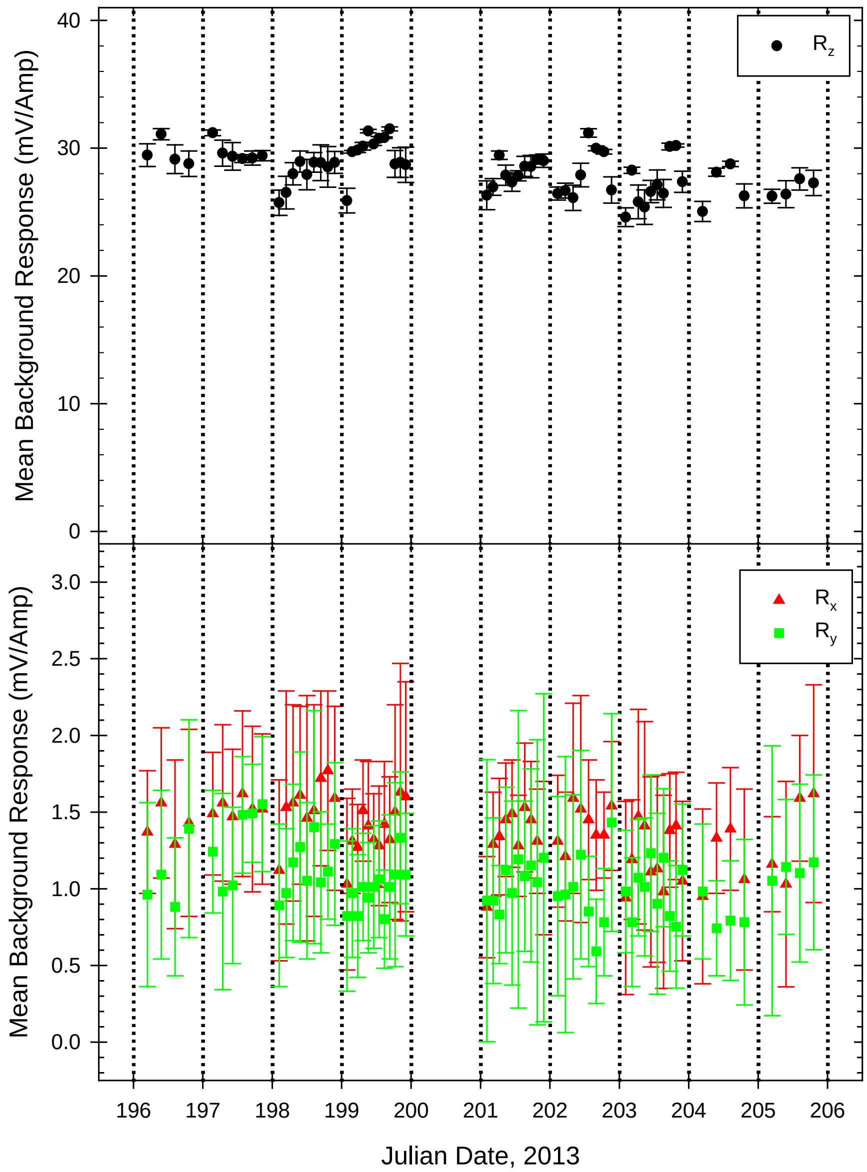

Figure 7-4 – Intra- and inter- daily variations in the response of the MP System to background anomaly-free areas through the duration of the demonstration. The upper panel plots the average measured signal of the four monostatic, Z-axis quantities at 0.089 ms, while the bars represent the standard deviation of those quantities (i.e. 1σ about the mean). The red and green points in the lower panel plot the average measured signal of the four monostatic, X- and Y-axis quantities at 0.089 ms, respectively.

8.0 COST ASSESSMENT

8.1 COST MODEL

The cost elements tracked for this demonstration are detailed in Table 8-1. The provided cost elements are based on a model developed for cost estimation for the MP System at Camp Beale in 2011 [6]. The model assumes a two-person field crew and one data analyst. For this site a third person was required due to the litter-mode deployment. While the MP system is not currently commercially available, an estimated daily rental rate is provided for comparison to other technologies. The rental rate is based, in part, on the costs of items purchased in prototype quantities (single units) and would presumably decrease significantly if the items were procured at production quantity levels.

8.2 COST DRIVERS

Two factors were expected to be strong drivers of cost for this technology as demonstrated. The first is the number of anomalies which can be surveyed per day. Higher productivity in data collection equates to more anomalies investigated for a given period of time in the field. The time required for analyzing individual anomalies can be significantly higher than for other, more traditional methods and could become a cost driver due to the time involvement. The thoughtful use of available automation techniques for individual anomaly analysis with operator QC support can moderate this effect.

In the cost model presented in Table 8-1, the data processing costs listed are for data QC and for parameter estimation using the industry-standard single-dipole model solver. In a heavily-cluttered environment such as the MMR CIA, routine use of the multi-dipole model solver, or multi-solver, was indicated and was used. Also no specific cost element was listed for the classification process. As the classification process is ongoing, no cost estimate is given at this time. However, the experience so far indicates that when use of the multi-solver is required, significantly more computer time is required to model the data. While more computer time is required, additional data analyst time is not typically required during the processing. Significantly more data analyst time is required however to evaluate the results of the multi-solver and to incorporate them into the classification pipeline. The cost model will continue to be updated for continued use in the future as additional cost data become available.

8.3 COST BENEFIT

The main benefit to using a UXO classification process is cost-related. The ability to reduce the number of non-hazardous items that have to be dug or have to be dug as presumptively-hazardous items directly reduces the cost of a remediation effort. The additional information provided by these sensor systems significantly improved anomaly classification performance over traditional methods. If there is buy-in from the stakeholders to use these techniques, this information can be used to reduce costs.

Table 8-1 – TEMTADS MP 2x2 Cart Tracked Costs

Cost Element	Data Tracked	Cost
Data Collection Costs		
Pre/Post Survey Activities	Component costs and integration costs • Spares and repairs	 $3,500
	Cost to pack the array and equipment, mobilize to the site, and return • Personnel required to pack • Packing hours • Personnel to mobilize • Mobilization hours • Transportation costs	$12,450 1 16 3 8 $7,250
	Cost to assemble the system, perform initial calibration tests • Personnel required • Hours required	$780 3 2
Survey Costs	Unit cost per anomaly investigated. This will be calculated as daily survey costs divided by the number of anomalies investigated per day. • Equipment Rental (day) • Daily calibration (hours) • Survey personnel required • Survey hours per day • Daily equipment break-down and storage (hours)	**$7.15 / anom.** $190 0.5 2 8 0.5
Processing Costs		**$10.85 / anom.**
Preprocessing	Time required to perform standard data clean up and to merge the location and geophysical data.	3 min/anomaly
Parameter Estimation	Time required to extract parameters for all anomalies.	2 min/anomaly

9.0 SCHEDULE OF ACTIVITIES

Figure 9-1 gives the overall schedule for the demonstration including deliverables.

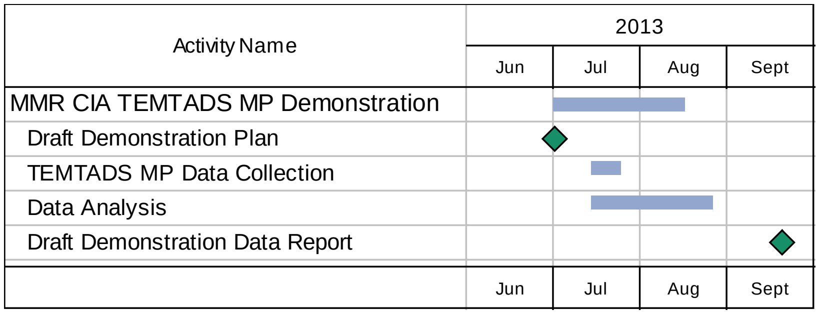

Figure 9-1 – Schedule of all demonstration activities including deliverables.

10.0MANAGEMENT AND STAFFING

The responsibilities for this demonstration are outlined in Figure 10-1. Dan Steinhurst (Nova Research) was the PI of this demonstration. Dan Steinhurst filled the roles of Site / Project Supervisor. John Breznick was the project lead for NAEVA Geophysics. Cora Blits (NAEVA) was the Quality Assurance Officer. Glenn Harbaugh (Nova Research) was the Site Safety Officer. His duties included data collection and safety oversight for the entire team. Cora Blits, Alison Paski, and Jon Guillard (NAEVA) served as Data Analysts. Ben Dameron (NAEVA) and Andrew Benson (NAEVA) served as Data Acquisition Operators.

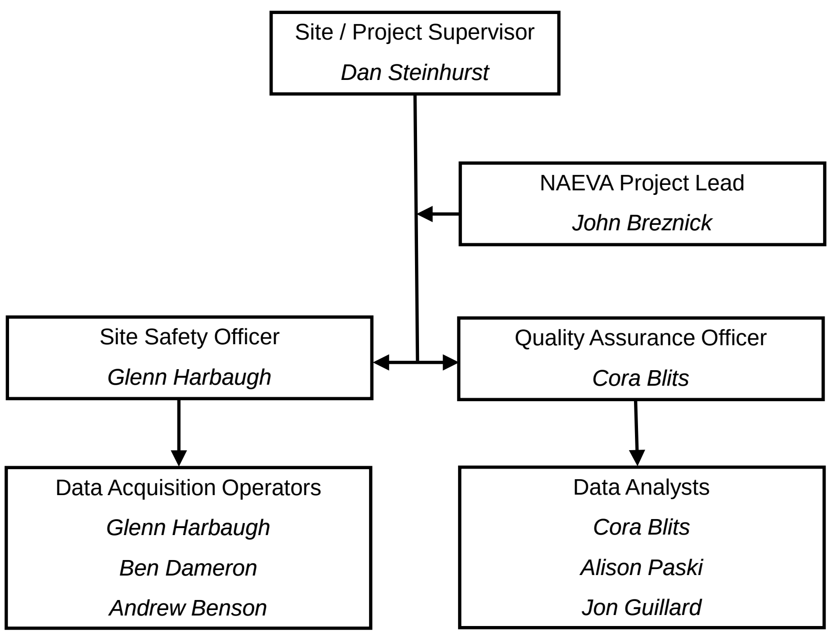

Figure 10-1 – Management and Staffing Wiring Diagram.

11.0 REFERENCES

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APPENDIX A. HEALTH AND SAFETY PLAN

An abbreviated Health and Safety Plan was generated for this demonstration. All emergency information such as contact numbers and directions to nearby medical facilities are provided in that document. The contents are reproduced here.

A.1 DIRECTIONS TO FALMOUTH HOSPITAL

Directions to the Falmouth Hospital in Falmouth, MA are as follows, starting at the main gate to Camp Edwards on Connery Avenue. See Figure A-1 for the overall route.

1) Head Northeast on Connery Avenue for 1.4 miles.
2) At the traffic circle, take the 3rd exit onto MA-28 South, drive for 9.1 miles.
3) Turn Right onto Ter Huen Drive, drive for 0.1 miles.
4) Turn Left onto Bramble Bush Drive, Falmouth Hospital is on the Right.

Falmouth Hospital is located at 100 Ter Heun Drive, Falmouth, MA 02540, (508) 548-5300. The total distance to travel is 10.6 miles and should take 15 minutes.

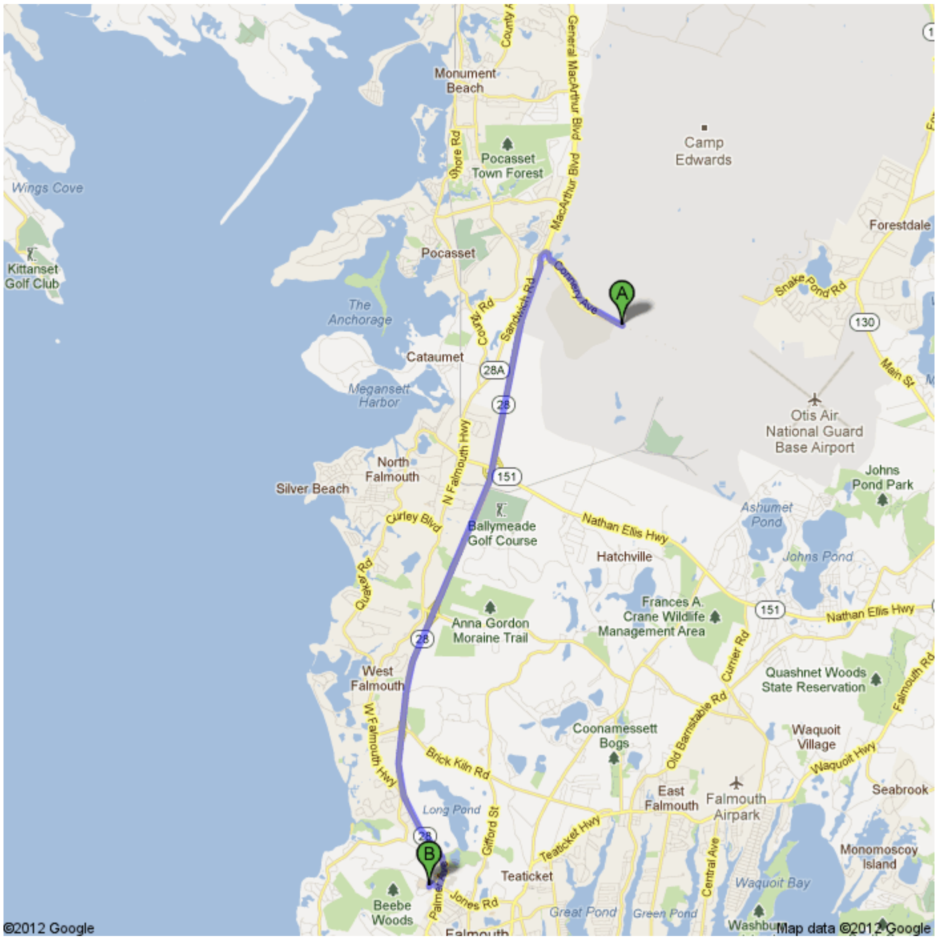

Figure A-1 – Area map showing the location of the Falmouth Hospital with respect to Camp Edwards.

A.2 EMERGENCY TELEPHONE NUMBERS

Telephone numbers for medical fire and other emergencies will be available on site for use by all project personnel in the event of an emergency and are provided in Table A-1. All vehicles will contain a cellular phone (including the phone list) to allow emergency communications in the event of an accident. The telephone area code for this area is 508.

Table A-1 – Emergency Contact Numbers

Agency	Emergency Phone Number	Non-Emergency Phone Number	Location
Bourne Fire Department	911	(508) 759-4412	130 Main Street, Buzzards Bay, MA 02532
Cape Cod Ambulance		(508) 833-3928	15 Jan Sebastian Drive Sandwich, MA 02563
Bourne Police Department	911	(508) 759-4451	175 Main Street, Buzzards Bay, MA 02532
Falmouth Hospital		(508) 548-5300	100 Ter Heun Drive, Falmouth, MA 02540
CVS/pharmacy		(508) 759-1097	6 Head of the Bay Road, Bourne, MA, 02532
Regional Center for Poison Control and Prevention		(800)-222-1222	http://www.maripoisoncenter.com/

APPENDIX B. POINTS OF CONTACT

POINT OF CONTACT	ORGANIZATION	Phone Fax e-mail	Role in Project
Dr. Anne Andrews	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08 Alexandria, VA 22350-3605	571-372-6565 (V) 571-372-6386 (F) anne.andrews@osd.mil	Acting Director, ESTCP
Dr. Herb Nelson	ESTCP Program Office 4800 Mark Center Drive, Suite 17D08 Alexandria, VA 22350-3605	571-372-6400 (V) 571-372-6386 (F) 202-215-4844 (C) herb.nelson@nrl.navy.mil	Program Manager, MR
Mr. Daniel Reudy	HydroGeoLogic, Inc. 11107 Sunset Hills Road, Suite 400 Reston, VA 20190	703-736-4531 (V) druedy@hgl.com	Program Manager's Assistant, MR
Dr. Dan Steinhurst	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	202-767-3556 (V) 202-404-8119 (F) 703-850-5217 (C) dan.steinhurst@nrl.navy.mil	PI
Mr. Glenn Harbaugh	Nova Research, Inc. 1900 Elkin St., Ste. 230 Alexandria, VA 22308	804-761-5904 (V) glenn.harbaugh.ctr@nrl.navy.mil	Site Safety Officer
Mr. John Breznick	NAEVA Geophysics, Inc. P.O. Box 7325 Charlottesville, VA 22906	434-978-3187 (V) jbreznick@naevageophysics.com	General Manager

APPENDIX C. DATA FORMATS

C.1 TEM DATA FILE (*.TEM)

These data files are a binary format generated by a custom .NET serialization routine. They are converted to an ASCII, comma-delimited format in batches as required. Each file contains 4 data points, corresponding to each transmitter (Tx) cycle. Each data point contains the Tx transient and the corresponding 12 receiver (Rx) transients as a function of time. A pair of header lines is also provided for, one overall file header and one header per data point with the data acquisition parameters. A partial example is provided below.

Line 1 - File Header

```
TargetID,Bkgnd,Date,CPUms,GPSUTC,Lat,Lon,HAE,GPSFixQ,UTM_Zone,UTM_E,UTM
_N,Elev,Heading,Pitch,Roll,Delt,BlockT,nRepeats,DtyCyc,nStk,AcqMode,Gat
eWid,GateHOff,TxSeq,GateT,TxI_Z,Rx1Z_TxZ,Rx1Y_TxZ,Rx1X_TxZ,Rx2Z_TxZ,Rx2
Y_TxZ,Rx2X_TxZ,Rx3Z_TxZ,Rx3Y_TxZ,Rx3X_TxZ,Rx4Z_TxZ,Rx4Y_TxZ,Rx4X_TxZ
```

Line 2 - Data Point Header

```
4,0,5/28/2013,36985640.625,134934.30,38.409854552,-77.10894215,-
33.570,4,18,315866.183,4253396.760,,253.956,3.98442,-2.81274,2E-
06,0.9,9,0.5,18,2,0.05,5E-05,1

4                  - Target ID
0                  - Background file Boolean (1 = background)
5/28/2013          - Collection date
36985640.625       - Start time in ms on CPU clock
134934.30          - UTC time of data collection
38.409854552       - GPS Latitude (decimal deg.)
-77.10894215       - GPS Longitude (decimal deg.)
-33.570            - Height-above-ellipsoid (m)
4                  - GPS Fix Quality
18                 - UTM Zone
315866.183         - UTM Easting (m)
4253396.760        - UTM Northing (m)
                   - GPS Elevation (m) – intentionally left blank
253.956            - IMU Yaw (deg, magnetic North referenced)
3.98442            - IMU Pitch
,-2.81274          - IMU Roll
2E-06              - Time step for transients (seconds)
0.9                - Base period length (seconds)
9                  - Number of Tx cycles in a base period
0.5                - Duty cycle
18                 - Number of base periods averaged (or stacked)
2                  - Data Acquisition Mode (Decimated Decays)
0.05               - Gate width as fraction of its own time
5E-05              - Hold-off time (seconds) for first data point
1                  - Tx coil ID number
```

Line 3 - First Data Line in First Data Point

```
,,,,,,,,,,,,,,,,,,,,,,,,,2.5E-05,0.491852843863786,-
0.0019447468039619,-
0.00167008188106537,0.00125536061090642,0.000316940817640296,0.00032090
2009700342,-0.000864236384734167,0.00112260623919521,-
0.000175718325757418,0.000508878029254883,0.000640205921826291,0.001023
92797989884,-0.000598618916918521
```

C.2 LOCATION AND ORIENTATION DATA FILE (*.GPS)

```
,Latitude/Easting/Pitch,Longitude/Northing/Roll,HAE/Zone/Yaw,Samples/UT
C,FQ_0,FQ_1,FQ_2,FQ_3,FQ_4,FQ_5
GPS,38.409854552,-77.10894215,-33.570,20,0,0,0,0,20,0
UTM,315866.183,4253396.760,18,134934.30
IMU,3.98442,-2.81274,253.956,20
```

These data files are ASCII format, comma-delimited files. A header line is provided.

Line 1 – Header information

Line 2 – Raw GPS data

```
GPS                 - Data Type Identifier
38.409854552        - Latitude (decimal deg)
-77.10894215        - Longitude (decimal deg)
-33.570             - Height-above-ellipsoid (m)
20                  - Number of samples received
0                   - Number of samples with FQ 0
0                   - Number of samples with FQ 1
0                   - Number of samples with FQ 2
0                   - Number of samples with FQ 3
20                  - Number of samples with FQ 4
0                   - Number of samples with FQ 5
```

Line 3 – Computer Location data

```
UTM                 - Data Type Identifier
315866.183          - UTM Easting (m)
4253396.760         - UTM Northing (m)
18                  - UTM Zone
134934.30           - UTC Time
```

Line 4 – IMU Data

```
IMU                 - Data Type Identifier
3.98442             - IMU Pitch (deg)
-2.81274            - IMU Roll (deg)
253.956             - IMU Yaw (deg, magnetic North referenced)
20                  - Number of samples received
```

C.3 FIELD NOTES FILE (*.TXT)

```
Cart Rolled: False
Interference with Measurement: False
Recentered Array: False
Data Issues: True
Can't Center on Target: False
4-inch Aluminum sphere
```

These data files are ASCII format, comma-delimited files. No header line is provided.

Lines 1 (- 6) – Standardized button information, if defined

Final Line – Comments, if any

C.4 ANOMALY PARAMETER OUTPUT FILE

The *UX-Analyze Advanced module* for Geosoft's *Oasis montaj* will be used to analyze the TEMTADS data. The fitted parameters for each investigated anomaly are distributed as an Excel 2010 spreadsheet, but an excerpt is given in .csv format below for reference purposes. A header line is provided for information followed by a 109-line block for each anomaly. The first line of each block contains the time gate-independent fit parameters and the remaining 108 contain the time gate-dependent parameters for each anomaly.

```
Anomaly_ID,Anomaly_X,Anomaly_Y,Anomaly_Amplitude,Fit_X,Fit_Y,Fit_Depth(
m),Fit_Phi(deg),Fit_Theta(deg),Fit_Psi(deg),Fit_Coherence,Time_Gate,Bet
a1,Beta2,Beta3

28,402751.00,4369521.75,234.34,402750.926,4369521.686,0.151,250.42,2.02
,76.57,0.99612,,,,
,,,,,,,,,,,1,1.47E+00,1.05E+00,1.08E+00
,,,,,,,,,,,,.,.,.,.
,,,,,,,,,,,,.,.,.,.
,,,,,,,,,,,,.,.,.,.
,,,,,,,,,,,108,2.46E-05,-1.69E-05,-1.60E-04

33,402726.00,4369505.50,15.24,402725.835,4369505.588,0.422,96.25,16.45,
5.26,0.96448,,,,
,,,,,,,,,,,1,1.71E+00,1.23E+00,1.18E+00
,,,,,,,,,,,,.,.,.,.
,,,,,,,,,,,,.,.,.,.
,,,,,,,,,,,,.,.,.,.
,,,,,,,,,,,108,6.56E-04,-1.91E-03,-1.57E-04
```